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ORIGINAL PAPER

Economic valuation of water storage function of forest ecosystems (case study: Zagros Forests, Iran)

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Abstract: Forest ecosystem services contribute to human welfare, both directly and indirectly. Here the economic value of water conservation by Bazoft basin located in Zagros forests in western Iran was estimated, using simulation models and Geographic Information System (GIS) as a tool for analyzing the effects of ecological factors on ecosystem services. Rainfall-runoff simulation was carried out by using Curve Number (CN) method in HEC-HMS model. The model requires the inputs of land cover, soil and short term rainfall and discharge data. The efficiency of simulated model was revised using observed data and doing calibration stages. The role of forest on water retention and surface runoff reduction by devising four hypothetical scenarios and then the effects of land use changes associated with these scenarios on rainfall-runoff behavior of the region were determined. The results show that under the case of scenario one which assumes that the entire of basin area is covered by forests, total outflow would be in the minimum amount and rainfall initial loss will increase. Forest hydrological services related to water retention was economically assessed using Replacement Cost Method. Valuation results show that each hectare of Bazoft forests can store 84.8 m^3 water with 0.5 US$/ m^3 annual value. So the water retention value of each hectare of these forests will be 43US$. This could have positive economic consequences for the region and would help decision-makers in selecting appropriate and economically feasible development strategies.

Keywords: Bazoft River basin; curve number; economic valuation; replacement cost; runoff

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Introduction

Forest ecosystems provide multiple benefits to human society in general and the economic sub-system in particular (Reyes et al. 2002; Vedeld et al. 2007), besides producing timber, seeds, fodder and a few other marketable non-wood products. However, forest ecosystem services are not fully recognized by human societies. The economic valuation of these services has become one of the most significant and fastest evolving research areas in environmental and ecological economics (Guo et al. 2001; Grêt-Regemey et al. 2007). Costanza et al. (1997) valued the world ecosystem services in the range of USD 16–54 trillion per year. Chomitz and Kumari (1998) analyzed the economic valuation of forest ecosystem goods and services. Guo et al. (2001), Reyes et al. (2002), Guo and Gan (2002) and Calder (2002) discussed the roles of forest ecosystems in water retention and regulation. Moreover, some authors have also linked the ecosystem service quantification processes to economic valuation methods in a Geographic Information System (GIS) for valuing various ecosystem services under different landuse change scenarios (e.g. Eade and Moran 1996; Mallawaarachchi et al. 1996; Termansen et al. 2004; Grêt-Regemey et al. 2007). These studies demonstrate the significant role of forest ecosystem services in generating human welfare. However, the researches on the economic values of forests in Iran are rare. Several researchers, using the recommended average value by Costanza et al. (1997), estimated the annual value of Mangrove and Zagros forests in Iran as about US$9 908 (water regulation and pollution control, US$6 696) per hectare (Zare-Maivan et al. 1999; Zare-Maivan and Mojard-Ashenabad 1999). Amirnejad et al. (2005) estimated the existence value of north forests of Iran based on contingent valuation (CV) and dichotomous choice (DC), US$2.51 household/month or annual value of US$30.12 for a household.

Water retention is an important service of forest ecosystems. It is generally believed that deforestation increases the frequency and severity of floods (Courtney 1981; Kramer et al. 1997).

Many experiments indicated the reduced runoff from forested area as compared with those under sparse or no vegetation cover (Bosch and Hewlett 1982). In a case study in England, Clark (1987) showed that forest soils were several times as permeable as rangeland soils.

Forests in Iran like many other developing countries are facing an over utilization and land use conversion as a result of rapid population growth and strong economic pressures. Forest area per capita in Iran is only 0.2 ha, significantly lower than the global average level of 0.8 ha. Particularly in the recent four decades, about one-third of the forests (about 6 million ha) has been destroyed, i.e., 200 000 ha annual deforestation. The rate of deforestation is 2.3% for northern Iran and 1.1% for other parts of the country (Abbasi and Mohammadzadeh 2001; Agheli 2003). Zagros Mountain region is often perceived as economically non-profitable regions. Deforestation and land use change have reduced the capacity of water absorption and retention in the Bazoft River basin in that region. The loss of forest cover also leads to the increase in soil erosion and more destructive floods, the impediment of agricultural productivity, and the displacement of local people, consequently exacerbating the poverty. If current rate of deforestation continues in the region, flooding may increase further and cause greater economic losses. In this study, we estimated the economic value of hydrological services in the Bazoft River basin, a sub-Mediterranean forest in Zagros, Iran. Since forest catchments offer a variety of hydrological services, this study focuses on surface runoff reduction and water retention provided by forest cover. Economic valuation of these valuable and welfare enhancing service may help us to prevent rapid deforestation. Moreover, policy decisions are most frequently determined on economic criteria. So, this study can be an effective beginning point to better understand the interactions between human and rapidly changing ecosystems of Iran.

Materials and methods

Study area

The Bazoft River basin is located in the west of Charmahal va Bakhtiari Province, Iran (49°35′–50°30′E, 31°37′–32°39′N), a part of Zagros Mountains, and covers about 230 000 ha (Fig. 1). The altitude of the region varies between 900 m a.s.l. in the southern parts and 4 150 m in Zardkouh peak. The soil type is silty-clay (Jihad-e-Agriculture Organization 2007). The forest area is about 64 000 ha, accounting for 32.12% of the total land area of the basin. The Bazoft River with approximately 167 800 m length receives many tributaries, and continues toward the Karoon River. Therefore, the area is extremely important for the water courses of many rivers that serve as freshwater resource for local people. The average annual precipitation in the region is about 916.5 mm, falling mostly as rain while the average annual temperature is 10.1°C. The dominant tree species in the area is *Quercus persica* (Fattahi 1994; Ghazanfari et al. 2004; Pourhashemi et al. 2004). Also some other species like pistachio trees (*Pistacia mutica*) are existed as individual trees. The majority of rural communities of the region has low income and mostly depends on agricultural subsistence/production. Traditional logging and livestock grazing are causing rapid deforestation and soil erosion, and jeopardizing the potential of the region as source of hydrological benefits.

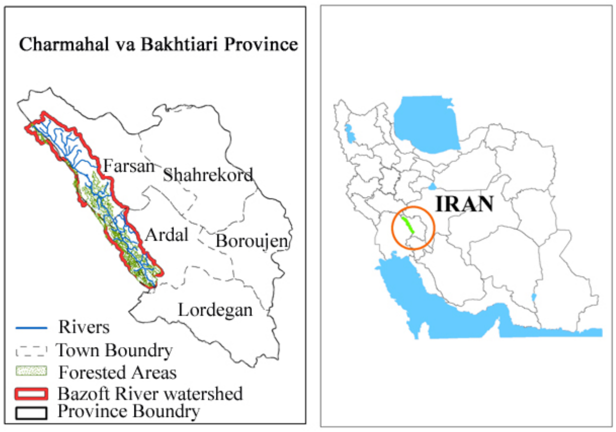

Fig. 1 The location map of Bazoft River basin

Methods

This study was conducted for (1) the determination and quantification of the forest hydrological services in water retention by using a rainfall- runoff model and GIS, and (2) economic valuation of these services using market price techniques. The function of water conservation by a natural forest ecosystem can be generally considered by the flow of rainwater in forests (Guo et al. 2001; Mabugu and Chitiga 2002). Here we have used NRCS Curve Number method for quantifying the effects of forest cover on water conservation and thereby calculated total outflow volume in the basin of interest. In this method, the depth of runoff produced by rainfall can be calculated by the following equation:

$$Q = \frac{(p-0.2S)^2}{p+0.8S} \quad p > 0.2S \tag{1}$$

where Q is the runoff depth (mm), P the rainfall depth (mm), and S the potential maximum soil moisture retention after runoff initiation which is related to interception, infiltration and surface depression. The Curve Number (CN) is also related to S as follows:

$$S = \frac{25400}{CN} - 254 \tag{2}$$

The CN is based on the soil hydrologic groups, land use, treatment and hydrologic condition, and has a range from 0 to 100 in which lower values indicate low runoff potential while larger numbers are for increasing runoff potential. The Soil

Conservation Service (SCS) has classified soils into four major hydrologic groups according to their infiltration rate as A, B, C and D. Group A is composed of soils with a low runoff potential and a high infiltration rate even when thoroughly wetted. Group B soils have a moderate infiltration rate when thoroughly wetted, while group C soils are those which have slow infiltration rates when thoroughly wetted and group D soils are those with a high potential for runoff, since they have very slow infiltration rates when thoroughly wetted. Runoff is affected by the soil antecedent moisture before a rainfall event. A curve number, as calculated above, may also be termed CN_{II}, or average soil moisture. The other moisture conditions are dry or CN_I, and moist, or CN_{III}.

As noted above, the ability of forest ecosystem in water conservation and surface runoff reduction varies significantly due to differences in the types of vegetation cover and soil. Because the study area is very heterogeneous in these factors, the homogeneous units map was developed. For this reason, the land use, land cover and the soil hydrologic group maps of the region were generated, overlaid and integrated in order to classify the basin into homogeneous units as the basic spatial input for the economic valuation.

The CN value of each unit was determined using the standard tables for CN_{II} and then the weighted average CN was calculated for the entire basin by the following equation (Mahdavi 2002):

$$\overline{CN}_w = \frac{CN_i \times A_i}{A} \tag{3}$$

Where, $\overline{CN}_w$ is the weighted average CN, CN_i the CN of the ith homogeneous unit, A_i the area of the ith homogeneous unit (ha), and A is the area of the total study area (ha). $\overline{CN}_w$ can be justified regarding to the condition of antecedent soil moisture in each rainfall event by the equations as follows:

$$CN_{(\mathrm{I})} = \frac{4.2CN(\mathrm{II})}{10 - 0.058CN(\mathrm{II})} \tag{4}$$

$$CN_{(\mathrm{I\Pi})} = \frac{23CN(\Pi)}{10 + 0.13CN(\Pi)} \tag{5}$$

Six paired rainfall-runoff events with a perfect hydrograph and without snowmelt effect were selected for simulation. A hydrograph plots the discharge of a river as a function of time. This activity can be in response to episodic event such as a flood. Then, the time of concentration and lag time of the basin were calculated. These variables indicate the response of a basin for a specific rainfall event at the outlet, and are primarily a function of the geometry of the basin. The input data were entered into the HEC-HMS model and the model was run for observed rainfall-runoff events. Then, the model was calibrated using CN parameter for getting better and more reasonable results.

The concept of economic value can be illustrated by comparing the hypothetical scenarios. In fact, scenario is about what will happen in the future. In this study, four hypothetical scenarios have been developed, including Scenario 1-total area of the basin converts to forestland, Scenario 2-total area of the basin converts to rangeland, Scenario 3-total area of the basin converts to farmland, Scenario 4-dense and semi dense forests convert to thinly scattered forests. The change in land cover can result in various hydrologic consequences. Therefore, we repeated the calculation process for the time of concentration and also lag time for the developed scenarios.

Finally, by means of Replacement Cost method, we quantified the value of the hydrological services (in terms of water conservation) provided by Bazoft forests. The Replacement Cost method is a valuation approach suitable for estimating the value of forests in water retention and is efficient where the mitigation and reparation activities due to some limitations are inevitable. The costs of replacement and construction of a similar environment provide a surrogate measure of the value of protective forest services. This technique has been used over the past years for valuing the water retained by forests on the basis of the costs spent for dam construction. So, the total value of reduced surface runoff by these forests can be annually estimated per hectare by having the costs spent for storing one cubic meter of water in dam. Thus, the construction costs of Karoon 4 dam was used in this study, which is under construction in the outlet of Bazoft River. The capacity of its reservoir is about 2.2×10^9 m^3 and its construction cost in 2007 is estimated about 1.12×10^6 US$ (Iran Water Resource and Energy Development company 2007).

Results

This study has illustrated the complexity of combining several disciplinary approaches to implement the Replacement Cost method for estimating the value of forest hydrological services in the case of Bazoft River basin. To estimate this value, first the whole study area was divided into 30 types of land cover and soil units, resulting 336 polygons (Fig. 2). Table 1 shows the types of land cover-soil units as well as their areas (ha) in Bazoft River basin. One polygon is represented by one of the 11 land cover types described in Table 1 and one of the three soil hydrologic groups (B, C and D).

The CN was determined for each existing land cover for average soil antecedent moisture condition as shown in Table 2. Weighted average CN according to Eq. 3 was 80 for the basin. Since the antecedent soil moisture was state I, therefore the basin adjusted CN using Eq. 4 was 62.7.

The results of time of concentration, lag time, initial loss and curve number calculations are shown in Table 3 and the results of model running only for one event (Apr. 4, 2004) are demonstrated as an example in Fig. 3. It has been occurred relatively violent raining in the basin that time.

Hydrologic parameters calculations were repeated for each of defined scenarios as wall as current condition scenario and then the model was run for each of them. The model simulates the outflow hydrograph based on these input data and gives the

volume of total outflow for different scenarios. The results of the modeling each scenario were summarized in Table 4.

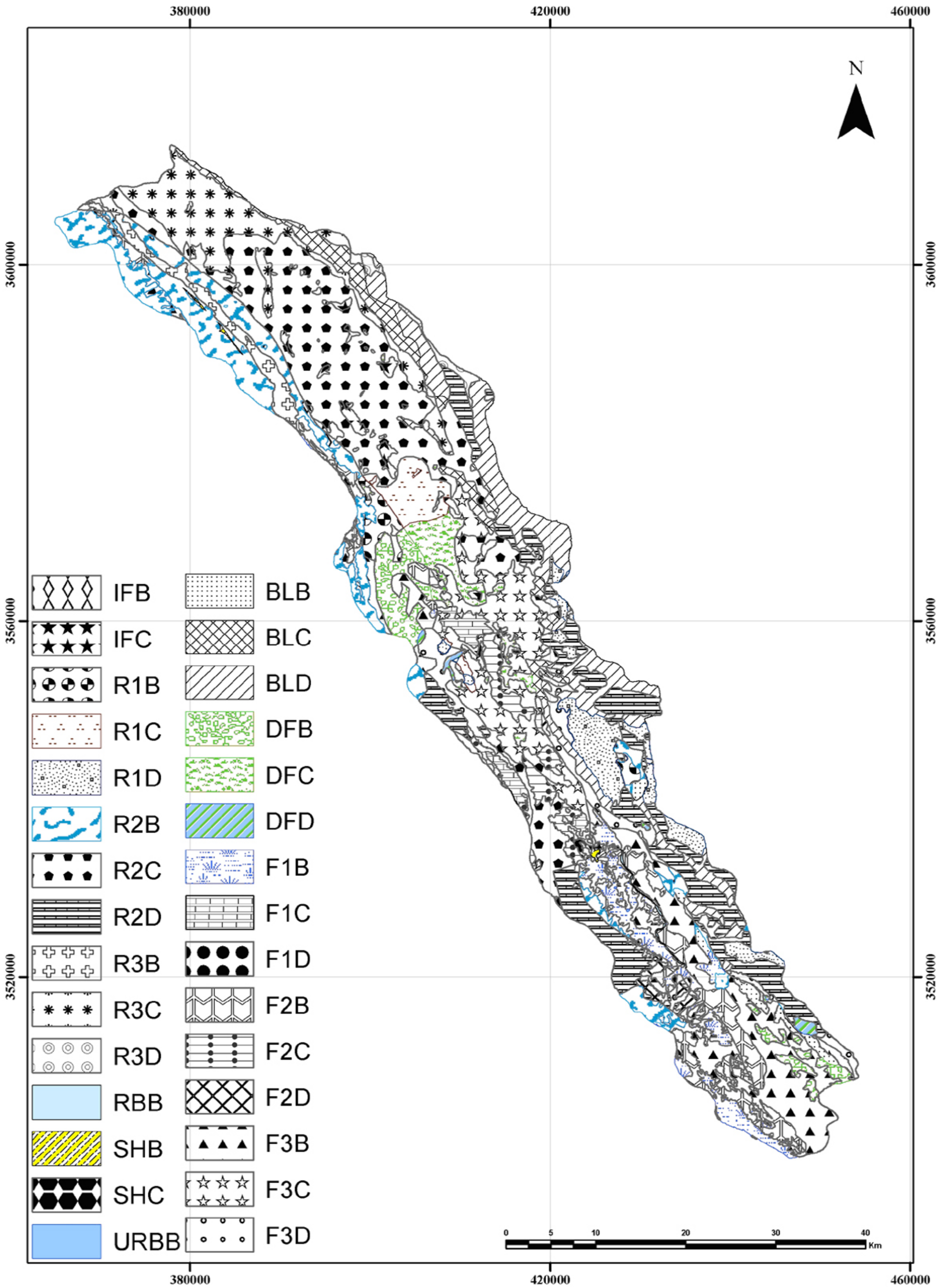

Fig. 2 Land cover-soil units in Bazoft River basin

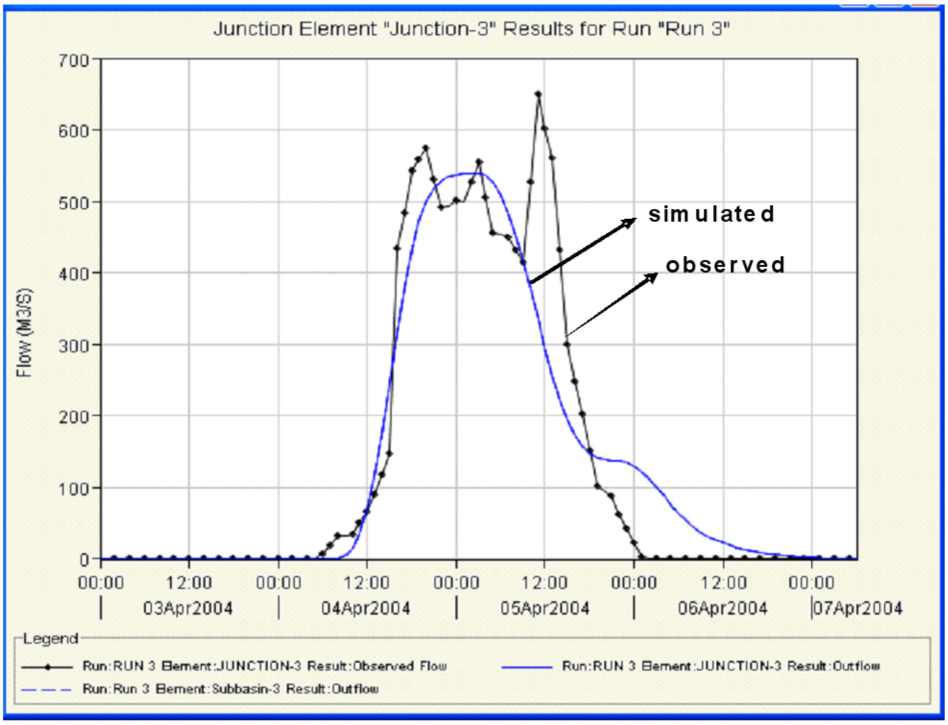

Fig. 3 The observed and simulated hydrographs for event in Apr. 4, 2004

Table 1. Thirty land cover-soil complexes and their areas (ha) in Bazoft River basin

Type of land cover	Type of soil		
	B	C	D
BL: Rangelands with less than 5% canopy cover and out crop	BLB: 1843.5	BLC: 7050	BLD:16222.4
DF: Dry farming	DFB:6392.8	DFC: 4826.5	DFD:733.2
F1: Forest with more than 50% canopy cover	F1B:7895	F1C:2595.5	F1D:272.3
F2: Forest with 25-50% canopy cover	F2B:11638.3	F2C:5357.3	F2D:1240.7
F3: Forest with 5-25% canopy cover (scattered trees)	F3B:21127.9	F3C:16237.3	F3D:7114.2
IF: Irrigated farming and orchards	IFB:637.5	IFC:3266.4	-
R1: Rangelands with more than 50% canopy cover	R1B:2838	R1C:4300.5	R1D:7849
R2: Rangelands with 25-50% canopy cover	R2B:20270.8	R2C:40153.3	R2D:20971.8
R3: Rangelands with 5-25% canopy cover	R3B:3872	R3C:14197.4	R3D:1206.2
RB, URB: Large river beds	RBB,URBB: 213.5	-	-
SH: Shrub lands with more than 10% canopy cover	SHB:186.8	SHC:176.9	-

Table 2. An appropriate Curve Number (CN) for current land uses in Bazoft basin for average soil moisture state (state II)

Current land uses	Treatment	Hydrologic condition	Hydrologic soil group		
			B	C	D
BL	-	Poor	79	86	89
DF	Row	Poor	76	84	88
F1	-	Medium	60	73	79
F2	-	Poor	66	77	83
F3	-	Poor	66	77	83
IF	Straight-row	Poor	77	85	89
R1	-	Medium	69	79	84
R2	-	Poor	79	86	89
R3	-	Poor	79	86	89
SH	-	Poor	66	77	83
RB,URB	-	-	95	-	-

Table 3. Curve number, T_{ime} of concentration, lag time and initial loss for rainfall events of interest

Curve number	Initial loss (mm)	T_{ime} of Concentration (min)	Lag time (min)
62.74	150.8	1150.8	690.48

Table 4. Curve number, lag time, initial loss and total outflow for each scenario

Scenario	Initial loss	Curve number	Lag time (min)	Mean total out flow($10^6 m^3$)
Current condition	22.93	68.9	645	34.43
1	50.5	49.66	1032	14.91
2	22.44	69.36	632	34.46
3	26.06	66.09	679	33.78
4	29.62	63.17	732	27.35

It is simply evident that in the case of scenario 1, the values of initial loss and lag time in the basin has increased while the CN value decreased. This result indicates the role of forest cover on the prevention of water loss and its retention in the soil. In contrary, in the other three scenarios, the parameters had no any significant difference with the current condition. The results of the mean total outflow show that the volume of infiltrated water in scenario 1 is about 19.521×10^6 m^3 which is greater than the similar amounts of the other three scenarios. This amount of water retained by forests has a considerable economic value and can be estimated using appropriate techniques such as Replacement Cost Method. The water retention value per unit area has been estimated by measuring the constructing costs of the Karoon 4 dam located in the outlet of the basin. According to obtained information, the total amount of proposed costs for this dam will be more than 1.12×10^6 US$, so the marginal cost of each cubic meter of water for Karoon 4 dam was estimated as 0.5 US$ in 2007. Taking into consideration that the amount of water conserved by forests in Bazoft region is about 19.521×10^6 m^3, one can state that the value of these forests in water retention, comparing with the costs spent for Karoon 4 dam construction, is about 10×10^6 US$. In other words, each hectare of the study area can retain about 84.8 m^3 water and has a value of about 43 US$. Table 5 shows similar calculations for the other three scenarios.

Table 5. The value of water retained by each hectare of the study area in different scenario (in US$)

scenario	The volume of infiltrated water($m^3\cdot ha^{-1}$)	value of each hectare (US$)
1	84.8	43
2	-0.16*	-0.08
3	2.82	1.4
4	30.73	15.2

*: The negative values in scenario 2 shows that water has not only infiltrated in this scenario, but also has been flown rather than current condition

Discussion

This study represents an effort to estimate the value of the hydrological services provided by forests in Bazoft River basin by focusing on surface runoff reduction. The valuation of ecosystem services should always be based on the estimation of the capacity of ecosystem function. Therefore, first we concentrated on the estimation of the forest hydrological services in water retention. Total surface runoff produced by each rainfall event was estimated using Curve Number (CN) method. The average weighted CN value for this basin was 80 which is a considerably high and indicates that a large amount of rainfall turn into runoff in each rainfall event. An increase of runoff height leads to increase in soil degradation, possibility of flood occurring and loss of accessible water for vegetation cover in the region of interest. This can result from deforestation and land conversion activities (Mahdavi 2002).

In order to reveal the forest role in hydrological benefits, the volume of forestland outflow was compared with similar amount that would result from likely alternatives scenarios. The hydrological results especially volume of total outflow for the scenarios showed that the volume of outflow in the forest (scenario 1) is minimum among the four scenarios, while for the case of rangelands (scenario 2) is maximum. A 1% increase of forest cover implies at least decrease in runoff by 0.29×10^6 m^3. This result is consistent with findings of different studies. For instance, Clark (1987) has found that forest soils were several times as permeable to rainfall as were pasture soils in England. Mirzayi (1996) in the study of economic valuation of Hyrcanian forests in northern Iran found that enclosed or under forest cover plots could decrease the runoff height by 16.92 mm. Moreover, Bruijnzeel (1990) and Bonell and Balek (1993) also pointed out that many processes such as overgrazing, road construction and the use of heavy machinery for land clearance involved in forest conversion. Compaction and gully erosion, in turn, increase runoff and decrease infiltration. Hamilton and King (1983) have reported severe reduction in infiltration following by heavy grazing in their study.

Forest hydrologists have accepted that forest cutting results in higher yields of stream flow (Bosch and Hewlett 1982), however, there has been no similar consensus on a cause-effect relationship between forest cutting in the head waters and floods in the lower basin (Hewlett 1982). The local soil and climate characteristics and the nature of land use that follow forest removal have important influences on the intensity of flooding (Bruijnzeel 1990). Also Komitz and Kumari (1998) stated that "the hydrological impact of converting a natural forest to a plantation might be quite different from converting it to annual cropping, and this conversion will affect the value of maintaining the land as forest". In general and as a principle it should be noted that the more forest removal, the more water loss is.

Replacement Cost method was used to estimate the economic value of the hydrological services of Bazoft forests. The value of water retention by natural forests, using data and assumptions outlined in the study and the costs spent for water storage in Karoon 4 dam, was 43.37 US$/ha per year. This dollar value represents the benefits from mitigation of flood damage and reduction of surface runoff caused by existing forest cover. While this estimation would be far lower than its actual value. As stated earlier, forest basins also have other hydrological benefits such as prevention of soil erosion, increasing crop yields, hydropower plants, etc. However, due to the lack of sufficient data and efficient methods, we could not assess every aspect of hydrological values of forest ecosystem of interest. Obviously, with taking into consideration of these valuable aspects, this estimated value will greatly increase. Boomabad Consulting Engineers (2003) have estimated the value of Zagros forests and rangelands in water retention about 79.4 US$/ha per year which seems to be similar with our findings. Panahi (2005) calculated this value for Hyrcanian forests, 31.33 US$/ha per year. It should be noted that generally the soil moisture in Zagros floristic region is far lower than Hyrcanian vegetative region which causes to supply more percentage of rain water by Zagros forests rather than Hyrcanian forests.

Also Guo and Gan (2002) showed that the maximum benefit of water retention in the Yangtze River basin can be obtained from the extension of forestland. Costanza et al. (1997) in the study of valuing the world's ecosystem services and natural capital, concluded that the majority of the value of services was currently outside the market system, and pointed out about 38% of the estimated value (US$ 33 trillion for 17 ecosystem services in 16 biomes) comes from terrestrial systems, mainly from forests and wetlands. However, the estimated values for hydrological function in similar studies are often different. In the case of Vohitra River basin in Eastern Madagascar for instance, the net value of the benefits from damage mitigation as a consequence of reduced deforestation was estimated 4.7 US$/ha (Kramer et al. 1997). Likewise, Adger et al. (1995) and Guo et al. (2001) have estimated the economic value of basin protection and water retention at 0.05 US$/ha for Mexican forests, and 67.3 US$/ha for forest ecosystems in Xingshan County of China, respectively.

The benefit levels are highly site-specific and scale-dependent. Habitats in general and forest in particular are internally quite heterogeneous. Any sizable forest area is likely to contain many varieties and densities of species, types of soil and terrain, climate, topography, drainage characteristics, land use and area that are more or less accessible to markets (Kramer et al. 1997). The role of forests in regulating stream flow should therefore be examined on a site-specific basis. Moreover, several hydrological processes are scale dependent: the dynamics of runoff, for instance, are quite different in 100, 10 000 and 1 000 000 ha basins. Scale also affects markets for forest products and services. As a result the values estimated for a small site can not easily be extrapolated to a large area and vice versa (Chomitz and Kumari 1998).

Clearly, for a developing country such as Iran, this calculated value would represent a significant economic gain for the region. The majority of rural settlements in Bazoft basin are low income communities dependent upon the forest lands for their subsistence. As abundant water is advantageous to spur the growth of the economy and to improve the living standard, this service of forest ecosystems can increase the economic effect of the region. This implies that if forest cover is preferred in relation to the provision of hydrological services and is to be guaranteed in the long term, the local residents would have to receive at least 43.37 US$/ha per year in terms of additional income in order to protect forest cover or commit themselves to reforestation activities. Moreover, these results can become useful tools for implementing green policy initiatives and sound conservation practices, such as market mechanisms for payment of specific hydrological environmental services by hydroelectric firms and large-scale agricultural industries. It also makes a cause for the inclusion of natural resource accounting in the calculation of the Gross Domestic Product (GDP). What this study abundantly clear is that ecosystem services provide an important portion of the total contribution to human welfare on this planet.

We must begin to give the natural capital stock that produces these services adequate weight in the decision-making process. A clearer understanding is required of the economic and other values of forests which are inherent in forest user's decisions and these values should be incorporated into decisions on the future management of forest resources. In this way, the current study is just an appropriate starting point.

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